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Optimization of Permanent Magnet Assemblies

A. R. Insinga*, R. Bjørk, A. Smith, C. R. H. Bahl

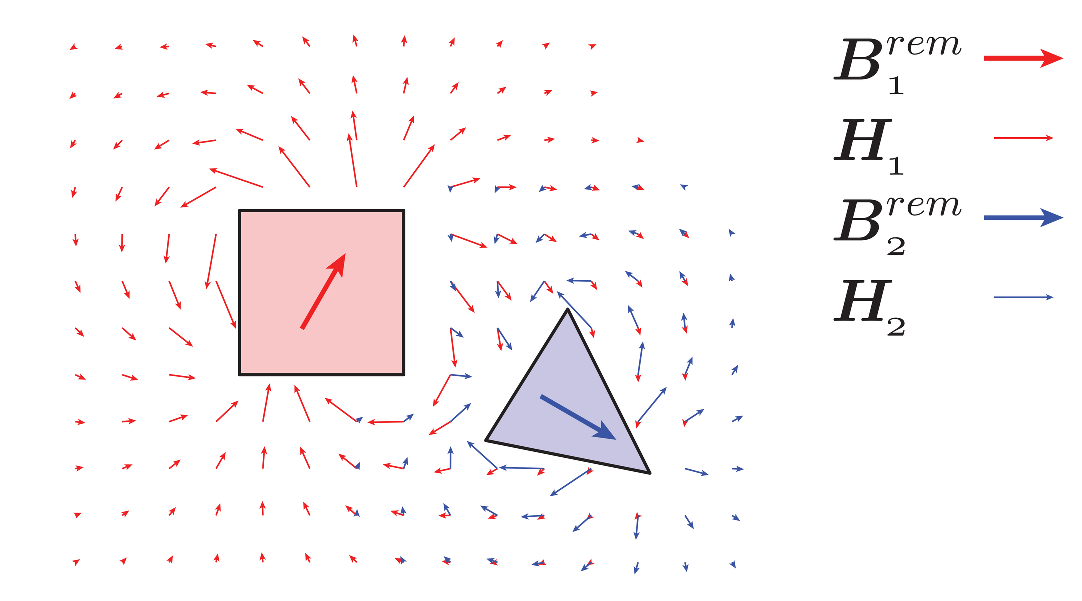

Fig. 1

We present a framework for the optimization of segmented magnetic structures which can be used with any objective functional $\mathcal{S}$, as long as all the materials exhibit a linear $\boldsymbol{B}$-$\boldsymbol{H}$ relation.
Our approach exploits the linearity of the field with respect to the remanence of each segment, allowing to quickly evaluate the objective functional $\mathcal{S}$ for any given configuration, and apply different optimization techniques, which would have otherwise been prohibitive.

Introduction:
Magnetic systems based on permanent magnet flux sources are fundamental in many scientific and technological applications[1]. In all the applications, the optimization of the magnetic system is of great importance. Many optimization algorithms, however, require a large number of evaluations of the objective functional and each evaluation requires the solution of the magnetic field equations for the considered geometry. This is often done by employing computationally expensive Finite Element Methods (FEM) and therefore many optimization algorithms are infeasible.

Methods:
Our method is based on the linearity of the generated magnetic field $\boldsymbol{H}$ with respect to the remanent flux density $\boldsymbol{B}^{rem}$ producing it. If the geometry of the system is pre-determined, and the permanent magnet is divided into N uniformly magnetized segments, it is possible to compute the field generated by each segment in any point of space as a linear combination of the components of its remanence vector[2]. The total field $\boldsymbol{H}$ is then given by the superposition of the individual field $\boldsymbol{H}_j$ generated by each segment.

$$\boldsymbol{H}(\boldsymbol{x}) = \sum_j^N \boldsymbol{H}_j\left(\boldsymbol{x}\ ;\ \boldsymbol{B}_j^{rem}\right)$$

This is illustrated in figure 1. We employ different optimization algorithms, such as: gradient descent, simulated annealing and the Nelder–Mead method.

Example 1 - Yoked Halbach Cylinder
As example of the interplay between geometry and objective functional, we consider the geometry of figures 2 and 3, optimized respectively for field intensity in the x direction averaged over the air gap, and field uniformity. The optimal remanence for each segment is indicated by a black arrow.
It can be noticed how the optimal solution is affected by the presence of the iron yoke only for the case of figure 2.

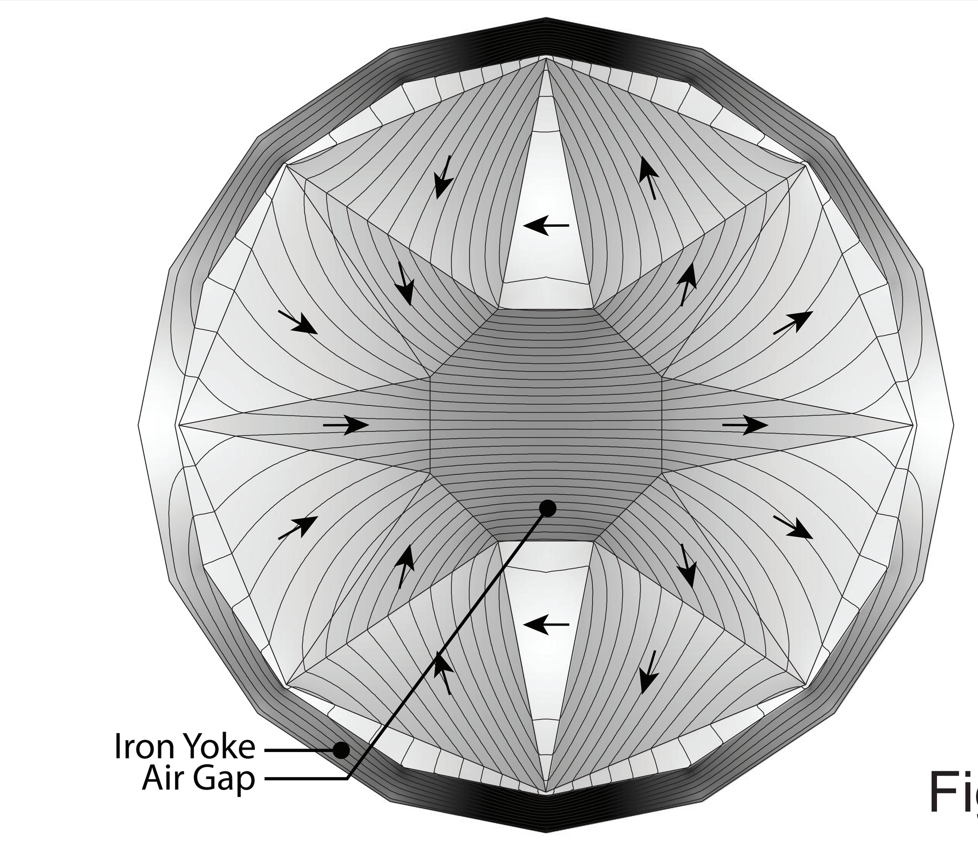

Fig. 2

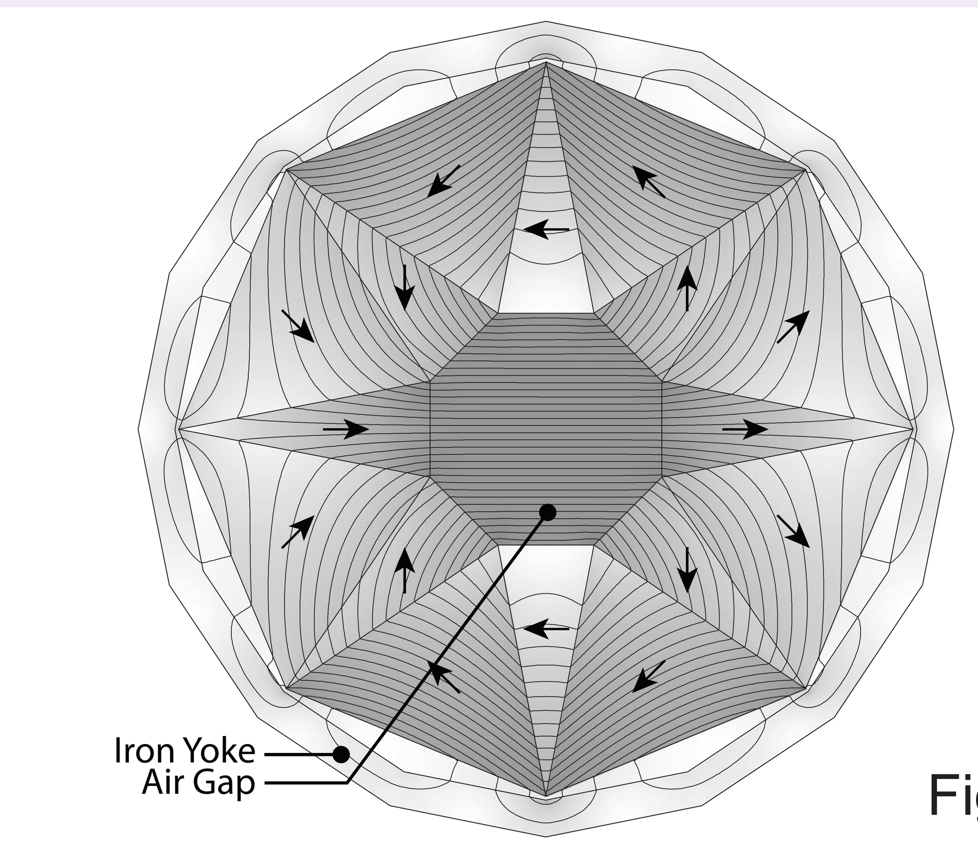

Fig. 3

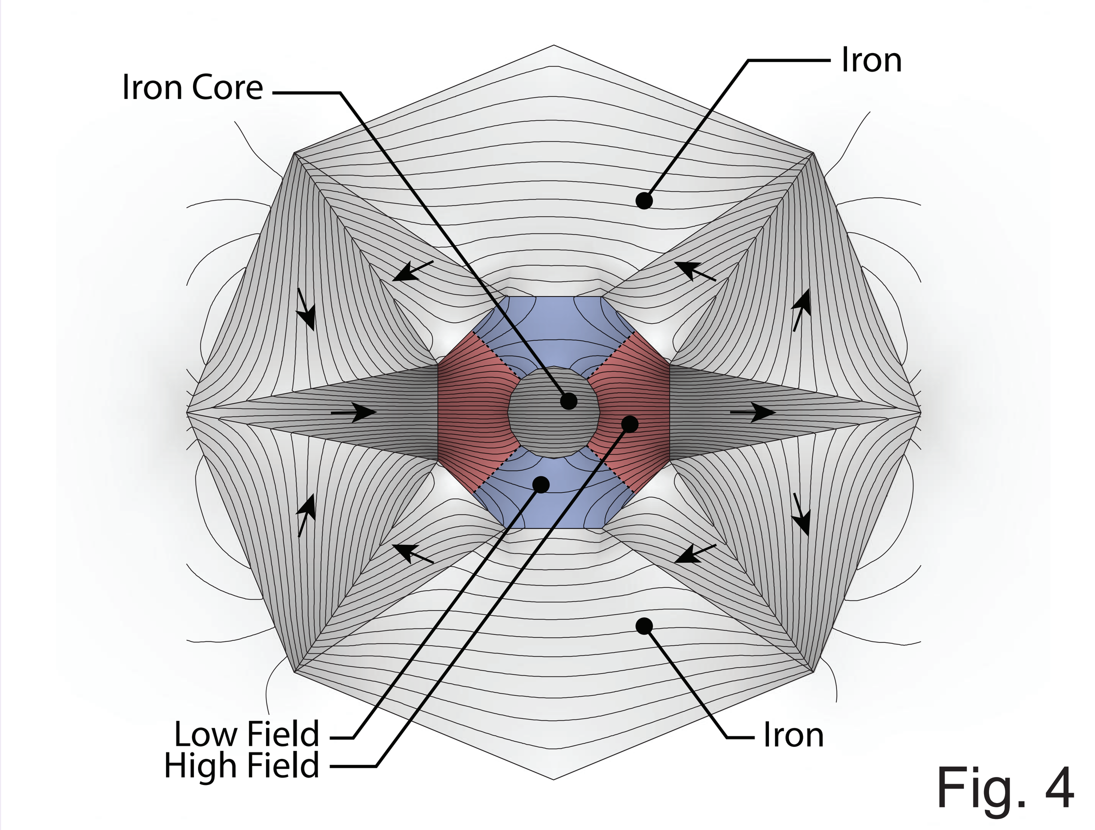

Fig. 4

Example 2 - Magnetic Refrigeration
Figure 4 illustrates the geometry for a device for magnetic refrigeration. The objective is to maximize the difference between the average norm of the field in the high field regions and the average norm in the low field regions[3], which are located in the air gap and indicated respectively by the red shade and the blue shade.

Conclusions
Our approach, which exploits linearity to quickly evaluate the field solution for a segmented magnetic assembly, can be used in combination with different optimization algorithms to optimize the direction of the remanence in each part of the assembly.
Our implementation allows the user to manipulate the solution in real time, and provides a great insight into the optimization process.

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